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Influencing factors to the friction charging in water delivery metal pipeline

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A B S T R A C T

Electrochemical reaction is the major influencing factor to the metal pipe corrosion, and the extra electric charge generated in the metal by the friction of the metal pipe with water flow will affect the electrochemical reaction and the corrosion process of the metal pipe. The effects of the kinds of water, the water flow rates and the installing of an electric charge trapper on the electric charge are investigated by measuring the current and voltage generated in the test pipe. The research results show that when using the deionized water as the test water, the current increases and the voltage decreases with the rising of the flow rate; the voltage generated in the case of using the city water has a different change from that of using the deionized water, it is smaller than that of using the deionized water with keeping it in static state, and then increases with the rising of the flow rate; however, with the increasing of the flow rate, the voltages generated in both cases of using deionized water and city water are close to a same value; the voltage generated in the case of installing the electric charge trapper is smaller than that of without the electric charge trapper. It is because that some electric charge in the water flow are caught by the electric charge trapper and then transported to the metal to neutralize an equal amounts of electric charge.

1. Introduction

In the water delivery industry, metal pipeline as the most practical transport tool has been widely used for many years. In the application of the water delivery pipeline, the service life of the pipeline is mainly influenced by the metal corrosion, and therefore it becomes the hot issue of research work in recent years [1]. According to the research results, it is known that there are some factors to influence the corrosion process, however, the electrochemical corrosion is considered to be the main way of the metal corrosion [2–6].

When the metal pipe is placed in an aqueous solution or in wet air, the micro-battery (also referred as corrosion cell) would be formed on the metal surface, and the electrode reactions could be written as follows.

$$Fe\text{-}2e^- = Fe^{2+} \tag{1}$$

$$H_2O + 1/2O_2 + 2e^- = 2OH^- \tag{2}$$

In the process of the corrosion reaction, there will be a certain electrode potential between the metal and the corrosion solution. However, when a current pass through the electrode of this micro-battery, the electrode potential will be changed, this is the so-called electrode polarization.

According to the frictional theory, the electric charge would be generated on the interface between the metal pipe and the fluid when the fluid flows through the metal pipe, and the electric double layer theory shows that one type of the electric charge remains in the metal side of the interface, and the other one of the opposite polarity charge exists in the fluid side of the interface [7–10]. As the fluid flows, the electric charge existing in the fluid side would be separated from the interface by the shear stress of the flow and get into the fluid flow, and it will make the interface to lose the electric neutrality and some electric charge to exist in the metal [11–14].

The electric charge will become the leakage current when an earth wire is set between the metal pipe and the earth, and under the action of the current, the polarization on electrodes of the

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micro-battery will be occurred. It is a common knowledge that either the anodic polarization or the cathodic polarization will lower the potential difference between the anode and cathode, and then influence the electrochemical corrosion of the metal pipe [15,16]. Therefore, if the electric charge remaining in the metal could be decreased, the electrode reactions would be restrained. For the above reasons, the factor of influencing the electric charge was investigated, and a method of decreasing the electric charge in the metal pipe was attempted in this study.

2. Experiment

2.1. Experiment installation

The experimental installation is shown as Fig. 1, comprised of water tank, circulation pump, inlet valve, flow meter, dissipation tank, insulating flange, test pipe, test wrapper (only used for voltage measurement), outlet valve, and measuring instrument (Keithley Model 2450 SourceMeter®, which has an enhanced sensitivity with 20 mV and 10 nA ranges and a high input impedance of more than 10GΩ, and whose resolution is 6.5 and basic measurement accuracy is 0.012%). The waters used in this study are deionized water and city water, and the ion content of the waters is shown in Table 1.

The circulation pump was used to keep the continuous cycle of the water in the system, the flow meter used to adjust the flow rate of water, and the dissipation tank used to leak the electric charge in the water before entering the test pipe and keep the water entering the test pipe without electric charge. The test pipe was surrounded by a test wrapper for inducing the equal potential from the electrostatic field formed by the accumulation of the electrostatic charge on the test pipe and blocking out the external influence when measuring the voltages [17,18]. The Keithley Model 2450 SourceMeter® was used to measure the induced potential generated on the test wrapper, and the leakage current by connecting the test pipe and the earth directly, and the insulating flanges were used to isolate the test pipe with other pipes.

A device called as "electric charge trapper" made of metallic iron as shown in Fig. 2 was placed inside the test pipe and perpendicular to the axis of the pipe, its area is much smaller than that of the pipe, and it was connected with the test pipe for catching the electric charge in the water and then carrying it to the test pipe.

Table 1
Ions content of the waters (mg/L).

	K	Ca	Na	Mg	Al	Fe	Mn	Cl
Deionized water	0.08	0.15	0.26	0.02	<0.01	<0.01	<0.01	1.43
City water	24.98	63.20	30.96	15.70	<0.01	0.01	<0.01	56.30

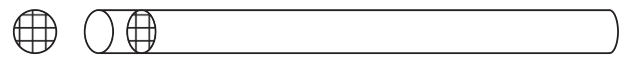

Fig. 2. Electric charge trapper.

2.2. Experiment process

The water was poured into the water tank, and then ran by the circulation pump. The rate of the water flow through the test pipe was controlled in 0, 15 L/min, 25 L/min, 35 L/min and 45 L/min, respectively. The current and the voltage generated in the test pipe were measured several times in every flow rate after the flow state was tending towards stability. The voltage installed the electric charge trapper was also measured in the same method as stated above.

3. Results and discussion

Fig. 3 shows the change in voltage generated in the test pipe with the flow state of the deionized water.

From the Fig. 3, it was known that the voltage changed obviously with the flow state. In the static state, the voltage was about 0.40209 V, however it decreased quickly to about 0.36262–0.37102 V when the deionized water began to flow, and changed obviously with the flow rate. When the water flow was stopped, the voltage increased again and then closed to the previous value in the static state. This result indicates that the change of the voltage is influenced by the flow state of the water.

Fig. 4 shows the change in voltage and current with the flow rate of the deionized water.

As shown in Fig. 4, the voltage reduced with the rising of the flow rate, however the absolute value of the voltage was increasing. The current also showed the same change tendency with the voltage and had a close correlation with the voltage. The above results indicate that the change of the voltage is because of the

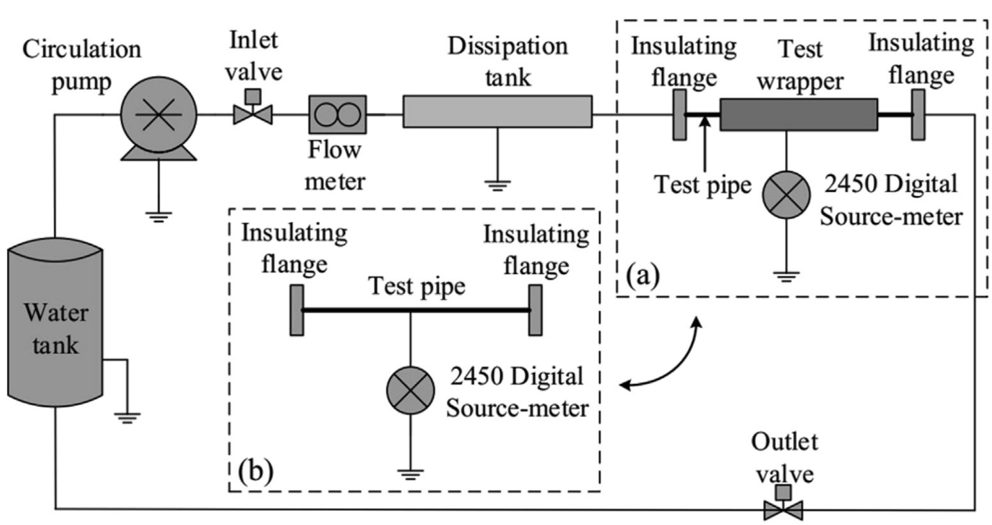

Fig. 1. Experimental installation ((a) For voltage measurement; (b) For current measurement).

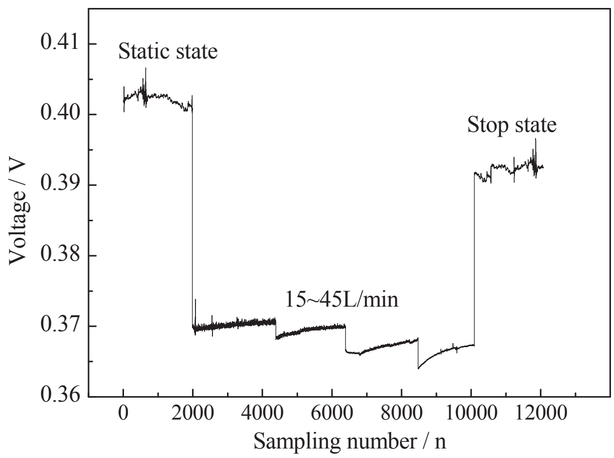

Fig. 3. Changes in voltage with the flow state of the deionized water.

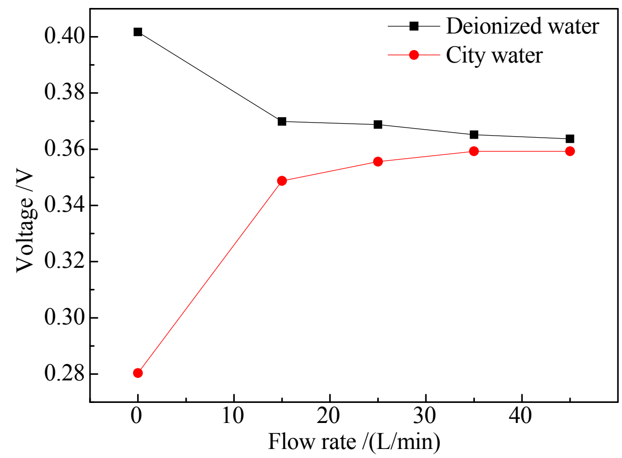

Fig. 5. Changes in voltage with the flow rates of the deionized water and the city water.

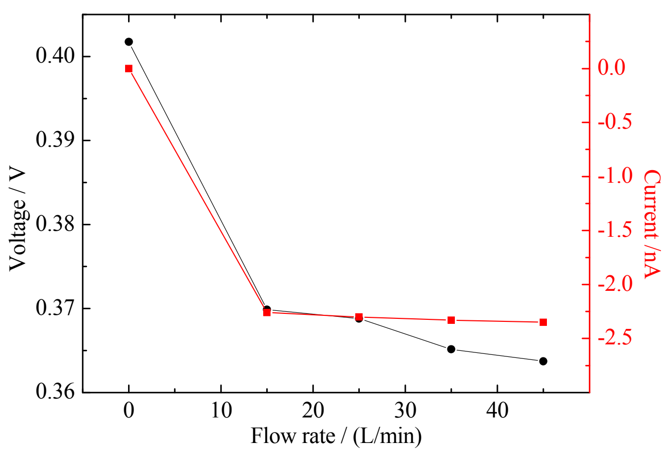

Fig. 4. Changes in voltage and current with the flow rate of the deionized water.

generation of the static charge by the friction between the test pipe and the water, and the current is produced by the static charge flowing from the test pipe to the earth.

The electric double layer is formed as the water contacts with the metal test pipe, the combination of them is mainly due to the electrostatic attraction and the interface chemical reaction. When the water without net charge is flowing through the metal test pipe whose both ends are isolated with the insulating flanges, the generation of the static charge is just by the friction between the pipe and the water and the separation of the electric double layer due to the relative frictional force is more than the electrostatic attraction, and the higher the flow rate is, the greater the relative shear stress is, and then the higher generation the static charge has.

Fig. 5 shows the change in voltage with the flow rates of the deionized water and the city water, respectively.

It was known that the voltage showed a different change tendency with the kinds of the test water. When the deionized water was used as the test water, the voltage decreased with the increasing of the flow rate, and changed from 0.40175 V to 0.36370 V as the flow rate increased from 0 to 15 L/min. In contrast, the voltage increased with the rising of the flow rate when the city water was used as the test water, and changed from 0.28034 V to 0.35929 V. When the flow rate of water increased over 15 L/min, the voltages showed a small change, however, there was a difference about 0.00441 V between the two waters.

According to the electric double layer theory, when the metal contacts with the water, there will be charged on the metal surface, because of the dissociation of some groups which adsorbed on the metal surface. For maintaining the electric neutrality, ions with opposite electric charge containing in the water will diffuse towards the metal surface to form the electric double layer.

Fig. 6 shows the model of electric double layer formed on the interface between the metal and the waters.

In the case of using the deionized water and keeping it in static state, there are some electric charge on the metal surface, owing to a little amount of ions contained in the deionized water as shown in Table 1 and its low electrical conductivity, therefore it causes the increase of the voltage between the metal pipe and the earth. In contrast, the voltage decreases when use the city water as the test water, because a large number of ions with opposite electric charge contained in the city water (see Table 1).

When the water begins to flow, the electric double layer formed in the static state is changed. According to the theory of friction, the positive and negative electric charge generates by the friction between the metal surface and the water, and exists in the both sides of the interface. At the beginning, the numbers of the positive and negative charge should be equal, however, some electric charge in the water side is carried away by the water flow, therefore the negative electric charge in the water side of the interface decreases with the increasing of the flow rate, and the positive electric charge remains in the metal side of the interface and influences the voltage

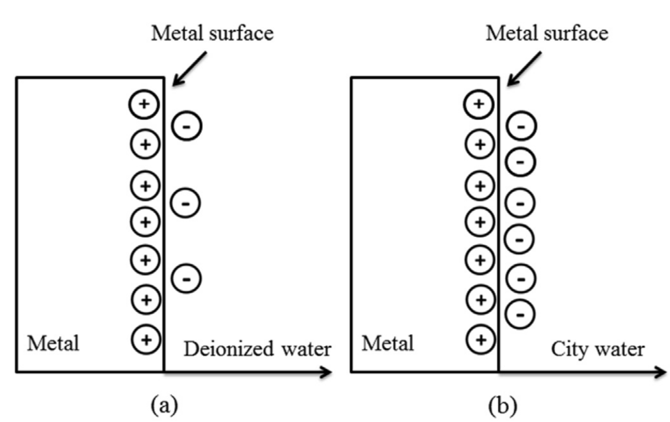

Fig. 6. Model of electric double layer formed on the interface between the metal and the waters.

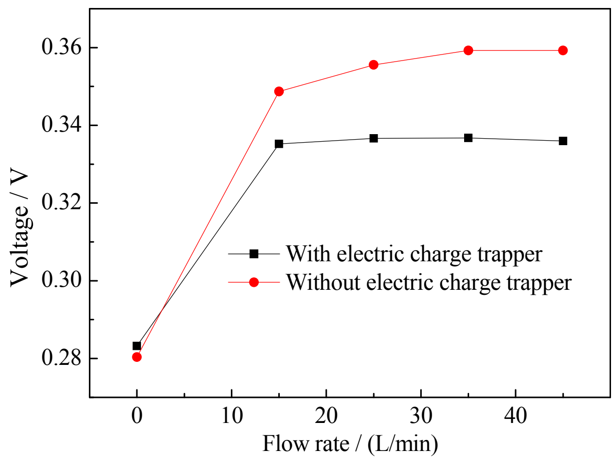

Fig. 7. Changes in voltage with the flow rates of the city water in both cases with and without electric charge trapper.

on the metal surface.

With the increasing of the flow rate, the voltages generated by the friction of the metal surface with both kinds of water are close to a same value. This means that the change of the voltage depends mainly on the flow rate and the effect of the ions containing in the water is small in the flowing state.

Fig. 7 shows the change in voltage with the flow rates of the city water in both cases with and without electric charge trapper, respectively.

From the result, it was known that the voltage generated in the case of installing the electric charge trapper was smaller than that of without the electric charge trapper. This indicates that the electric charge in the metal pipe decreases by installing the electric charge trapper which catches some electric charge in the water flow and then transports them to the metal side of the interface to neutralize the electric charge of opposite polarity. Therefore, the accumulation of the electric charge on the metal pipe wall will be restrained under certain conditions, and some of the electrostatic hazard can be prevented. The role of the electric charge trapper is small but even so it is significant because of its area is much smaller than the pipe area. So the new method of decreasing the electric charge on the metal pipe wall can be used with combining other technical methods in appropriate cases in the future.

4. Conclusions

The friction of the metal pipe with the water flow will cause the accumulation of the electric charge on the surface of the metal pipe, and it is considered to influence the electrode reactions and the corrosion process of metal pipe. The effects of the water kinds, the water flow rates and installing an electric charge trapper on the electric charge are investigated by measuring the voltage and current generated in the metal test pipe. The obtained conclusions are as follows.

(1) As the flow rate of the water increases, the generation of the electric charge by the separation of the electric double layer increases, and then the measured voltage and current generated on the surface of the metal pipe also increase.
(2) Different waters flow through the metal pipe can form different kinds of electric double layer, the effect of the friction between the metal and the water on the generation of the electric charge is greater than that of the ions content in the water.
(3) The voltage generated in the case of installing the electric charge trapper is smaller than that of without the electric charge trapper. It is owing to some electric charge in the water flow are caught by the electric charge trapper and then transported to the metal to neutralize an equal amounts of electric charge.
(4) In order to determine the safety of the water delivery and reduce the metal corrosion under different flow rates, it is necessary to further strengthen the measurement and research of the voltage and current on the pipeline.

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